BBC RD 1985/15

RESEARCH DEPARTMENT REPORT

SIGNALLING IN PARITY: a brief history

J.P. Chambers, M.A., M.I.E.E.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

December 1985

BBC RD 1985/15

SIGNALLING IN PARITY – A BRIEF HISTORY

J.P. Chambers, M.A., M.I.E.E.

Summary

Equipment built in BBC Engineering Research Department in 1974 for use on an experimental 120 Mbit/s digital link required no additional signalling capacity for multiplex control and synchronisation. This Report describes the general technique of 'signalling in parity' as used in that equipment and describes how it has found other applications over the last ten years in synchronisation, control and robust transmission of auxiliary data. The technique features in several new services such as the Radio-Data System (RDS), digital stereo sound for television (DSSTV) and the sound multiplex of the C-MAC/packet system for direct broadcasting by satellite.

Issued under the Authority of

M. E. B. Moffat

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

December 1985

(EL-177)

SIGNALLING IN PARITY – A BRIEF HISTORY

J.P. Chambers, M.A., M.I.E.E.

(EL-177)

SIGNALLING IN PARITY – A BRIEF HISTORY

J. P. Chambers, M.A., M.I.E.E.

1. Introduction

The broadcaster has a well-defined channel in which to carry the programme, and any extra information that is required to be carried has to be included in the available capacity. About 25% of the television waveform had to be reserved for synchronising pulses. The additional information required for colour television and stereo radio was added using subcarriers (involving minor degradations to the service areas). Ceefax took advantage of the spare capacity provided to allow for slow field flyback in early television receivers; if a similar service is required for HDTV it will need a positive decision to provide the spare lines.

There is no obvious equivalent to these techniques in a digital signal, if the gross bit rate is known and all the bits have already been allocated. However, there are ways of smuggling extra information in some of the existing bits. This Report describes a general method and gives examples of its use.

1.1 Parity bits

The use of the simple parity bit[1] in binary data handling probably first became important when mechanical means of recording and reading data were in use. An extra track on punched tape, carrying the parity bit, could be used to provide a rapid and reliable indication of failure of system (such as a burnt-out solenoid) or failure of medium (such as a hole bunged up with fluff). It was particularly useful where the data was divided into 'words' as the parity check could identify which word was in error. A simple parity check would not detect two errors, or any even number of errors, in a word but it was assumed that any systematic fault (such as the burnt-out solenoid) would necessarily have received rapid attention and that the other faults were not sufficiently frequent to occur twice in the same word at a significant rate.

Similar arguments applied to digital magnetic recording using parallel tracks where the words were laid 'across' the track. In this case it was common also to divide the words into blocks and to apply 'longitudinal' parity checks to all the bits of one track in each block to provide a block check character (BCC).[1] In principle, any single error in a block could be traced by the intersection of these orthogonal checks and then it could be corrected by inversion but it could never be known with certainty that there were no other errors present, or even that the apparent single erroneous bit was, in fact, in error.

Usually the data recorded in this way represented characters of text or numerals and punctuation coded according to a five- six- or seven-bit table such as International Alphabet No. 2[1] or ASCII. Many of these tables have the unfortunate property that groups of similar characters (notably the numerals) have similar codes so that isolated errors are likely to corrupt a message in such a way that the error is not obvious. In some cases, such as with financial information, the effect of changing one numeral to another can be very serious. Although a simple parity check can be a useful component of an error detection/correction strategy it is clearly inappropriate to depend on it in critical cases. Since February 1982 the BBC Ceefax transmissions have included a 16-bit cyclic redundancy check (CRC) on each page to allow suitably-equipped decoders to check, with a high degree of confidence, that each page has been received correctly and completely. This check is implemented in the Teletext Adapter for the BBC Microcomputer, both for normal pages and for 'telesoftware'.

It is now common to handle the analogue audio and video waveforms used in broadcasting as sampled and digitised signals. Each sample usually corresponds to one digital word protected by parity. Unlike text information, the error caused by an incorrect word can usually be effectively concealed by substituting a sample interpolated from nearby samples. This is because the signals are bandlimited and sampled at a sufficiently high rate, so there is interdependence between samples. In the case of television the nearby samples may be from adjacent lines, fields or pictures and not necessarily the immediately adjoining samples. The subject of sample interpolation and prediction has received considerable study in connexion with bit-rate reduction[2] and error protection[3] and it has even been proposed[4] that interpolated samples be used to identify and correct a suspected error in a single more significant bit.

1.2. The concept of signalling in parity

It has always seemed to the author that simple parity is a waste of valuable data capacity in applications, such as broadcasting, where this capacity is

limited and there are several competing uses. Simple parity is not at its best in the presence of a continuous high error rate. It uses too many bits to indicate that the channel is faulty and that messages should not be believed, and too few bits to allow errors at modest rate to be corrected.

When travelling by air the author invariably studies the road traffic before landing in order to establish with a high degree of reliability a single bit of information, whether he is over the British Isles or over the continent of Europe. This is the result of majority logic applied to whether each vehicle is advancing on the left- or right-hand side of the road. The system has proved infallible and it does not demand any unnecessary extra action by the drivers concerned. It is this observation which sowed the seed for the exploitation of signalling in parity.

The expression 'signalling in parity' is used to describe the technique whereby usually-predictable (i.e. redundant) information is systematically modified according to other information in a way which is completely reversible while the channel error rate is low. This other information can be recovered in the receiver. The 'usually-predictable' information may be, for example, an assembly of simple parity bits, a more elaborate check word or a fixed framing code. In the latter case the 'parity' refers to the variations in polarity of parts or all of the framing code.

Frequently the idea of signalling in parity has been criticised or even rejected on the grounds that it violates a fundamental principle that you cannot get "something for nothing". It will be seen later that there is a penalty paid for this extra signalling capacity, but it is predictable and it can be made very small.

2. Description of the principle

2.1 Object

The object of signalling in parity[5] is to enhance the data-carrying capacity of a digital signal by utilizing parity, synchronisation and other error checking signals to carry other information also. It is a further object that these supplementary signals be transmitted with a high degree of reliability. They are therefore suitable for the control functions which alter the method of interpretation of the data itself, for example those which change the format of a multiplex or alter the scaling factor of a companded sound signal.

The method is applicable to data transmitted by transmission line, radio, optical fibre etc. but it may equally well be applied to a recording/playback process.

2.2 General method

The general method common to all the applications described in this report is summarised in *Fig. 1.* The input to the channel comprises the data and data-dependent redundant signals (DDRS). These DDRS may be dependent on the content of the data itself such as simple parity checks or more complex check words, or they may be a function of the data format, such as framing words or continuity counts between successive packets of data. They are, strictly, redundant in that a locked decoder with an error-free channel could continue to function indefinitely without these signals but they have practical value in establishing initial synchronisation and recovering synchronisation after it has been lost, and in monitoring channel errors and indicating where and how corrective measures might be taken.

The distinction between framing and error protection is being deliberately blurred in this description, to show that the principle of signalling in parity applies to both or, more strongly, to suggest that they are inseparable or, in some cases, even one and the same. For example, error correction will only function correctly when framing is correct, and later examples show that this principle can be used to eliminate framing codes as such. Alternatively, if framing codes are retained as a convenient mechanism to avoid the continuing and gross errors caused by wrong framing, their very obvious redundancy allows them to be exploited directly as a vehicle for signalling.

In Fig. 1 (a) a conventional data transmission system is shown. The DDRS are sent together with the data itself. At the receiver the redundant signals are used together with the data itself and/or a timing 'flywheel' to initiate possible corrective action such as error concealment or data reframing.

In Fig. 1 (b) an extra data input accepts data which is used to control a pattern generator. The available patterns are a set of significantly different digital words used one at a time and selected according to the extra data. In the case where the extra data is for synchronisation purposes, rather than carrying a message, the pattern becomes a sequence repeating over the periodicity of the data format. Such a sequence can be stored explicitly in memory or it can be generated by a known algorithm. The DDRS are modified by the current pattern before transmission. In the examples given later this modification is always bit-wise addition

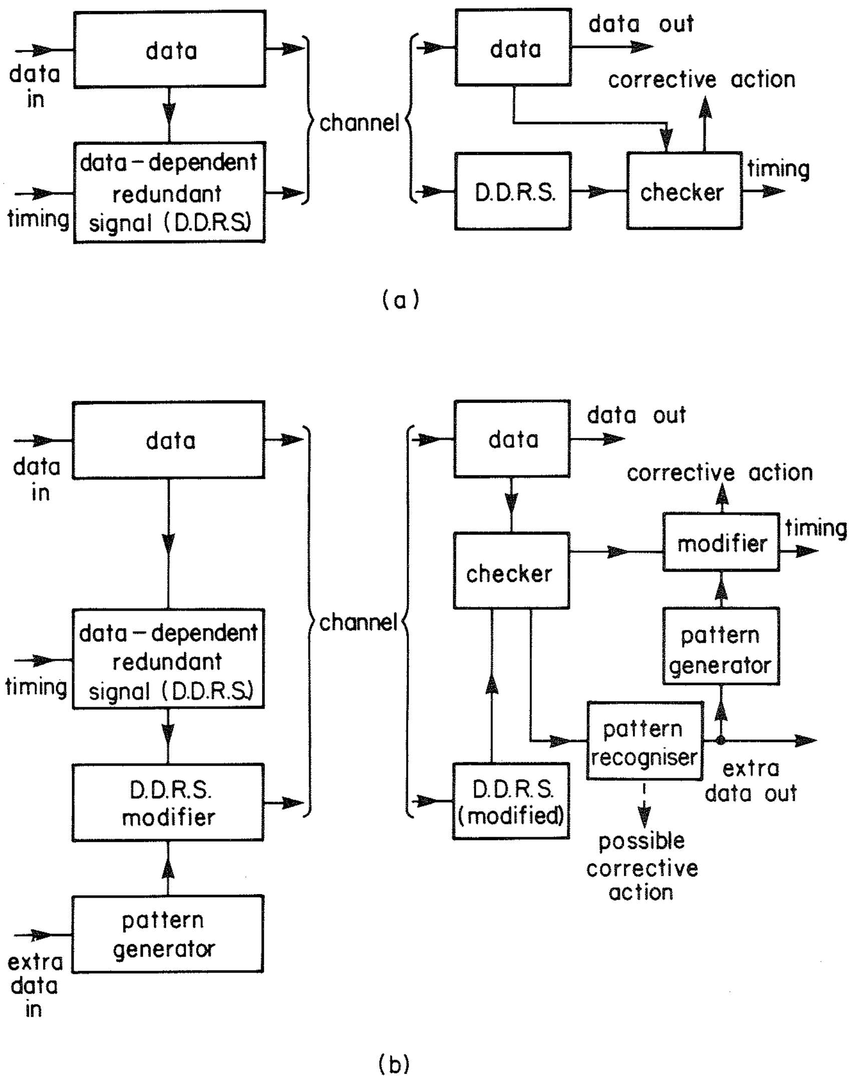

Fig. 1 — General method of transmitting extra data.
a) Conventional data transmission.   b) Augmented data transmission.

modulo-two, although alternative methods, preferably linear, could be devised.

In the receiver the DDRS is recreated from the received data and compared with the received DDRS. In the absence of errors the difference is the modification pattern which is recognised and interpreted. If errors are present the comparison may be imperfect, but a 'nearest match' can be found together with an indication of the apparent severity and significance of the errors. A gross error could cause a wrong 'nearest match', but the 'nearest match' is generally assumed to be the pattern that was sent and the modification is then 'undone' to reveal the conventional DDRS to be interpreted in the normal way. In cases where there is not a simple one-to-one relationship between data bits and DDRS bits a more elaborate decoding strategy may be appropriate, but still based on the principles of 'maximum likelihood'.

3. Examples of signalling in parity

3.1 The 120 Mbit/s Portsdown trial

In 1974 BBC Engineering Research Department, jointly with the (then) Post Office, were providing and using equipment to test a 150 km line with 72 repeaters between Portsmouth and Guildford and back again operating at an input/output data rate of 120 Mbit/s.[6] One of the test signals was a PAL television signal sampled at thrice subcarrier rate with each sample digitised as an eight-bit word with a ninth parity bit. This gave a gross bit rate of 119.707 706 25 Mbit/s with a residue of 292.293 75 kbit/s for word synchronisation, bit 'stuffing' and stuffing control.

The equipment designed to produce the 120 Mbit/s serial data stream from the thrice subcarrier nine-bit parallel data, and the complement-

ary equipment at the receiving terminal, provided word synchronisation and stuffing control without requiring any additional signalling capacity, so the entire residual capacity was available for auxiliary data services. It could accommodate variations of ± 25 p.p.m. in the ratio of the sampling frequency to the link clock rate and, if required, it could produce its own 120 MHz clock from thrice subcarrier with a fixed error of +68 Hz.

The format of the 120 Mbit/s serial signal used is shown in *Fig. 2*. The serial nine-bit words were taken in groups of 45 or 46, with a single auxiliary data bit between the groups. The length of each group was signalled by the choice of odd or even parity for the nine-bit words within the previous group, and the parity of the last word within each group was complemented to assist initial lock-up. The decision on the length of the blocks was taken according to the trend of the data rates, and very little buffer storage was required. The extremes of tolerance corresponded to all groups of length 45 and all of length 46. The nominal frequencies implied a mean group length of 45.505 . . . which meant an alternating pattern of group lengths 45 and 46 with occasional repeats of group length 46. In the closed-loop mode the pattern was a regular alternation which had the added benefit of giving very stable operation of the 120 MHz phase-locked loop.

In the receiving equipment word synchronisation was achieved by, in effect, testing all nine possible phases at the same time and looking for a consistent parity check. This could be done comfortably within the span of a block and the deliberate violation of parity at the end of the block allowed the slip of word phase to be anticipated. Once the system had locked up, which took only tens of microseconds, it continued to operate reliably even through deliberate high error rates. A slip between clock and data would have required the system to lock up again but such slips were not apparent in the link as used. The very low absolute jitter in the timing of the nine-bit words eased the regeneration of the thrice subcarrier clock at the output.

The source equipment produced a clock signal at the 292 kHz auxiliary data rate. This could have been used to control the admission of data from another source at that rate. In the system as built a simple delta modulator clocked at this rate provided a sound channel on the link.

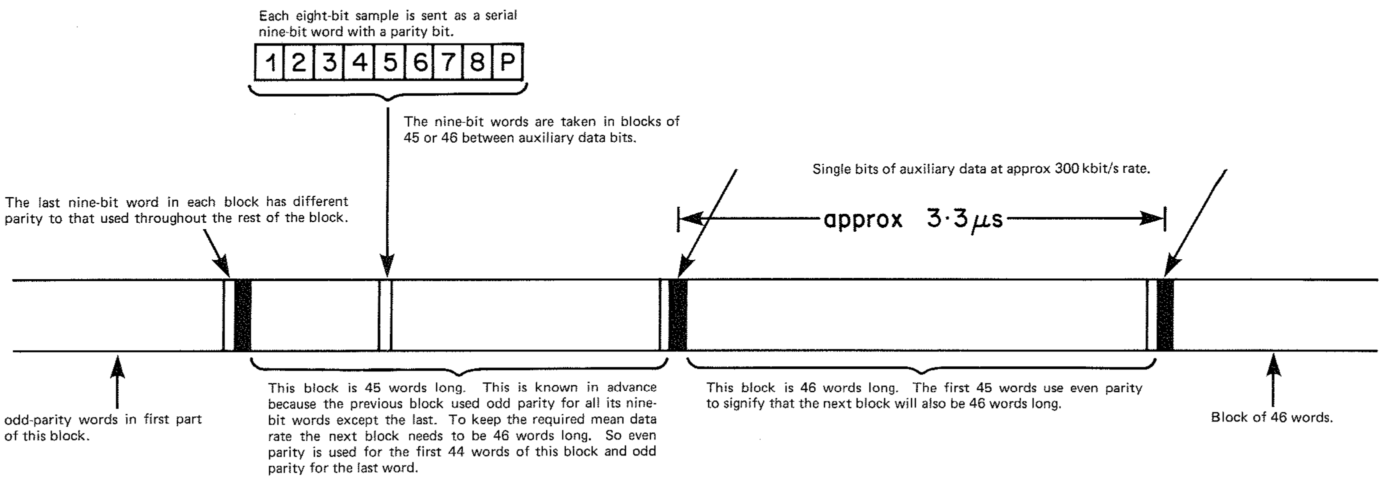

Fig. 2 – Format of 120 Mbit/s serial data stream used in 1974.

This example provides a clear case of 'something for nothing' in that no additional data was required to control the synchronisation or the insertion of the additional bits, all of which were available for use. As the details of the equipment were not published, and as it was only a component part of the field trial, it received little attention at the time, although its performance was exactly as expected.

The use of parity checking as a method of establishing and maintaining word synchronisation in serial-to-parallel converters has been a feature of several subsequent equipment designs.[7]

3.2 Digital sound coding proposal

During 1975/6 there was considerable activity within the EBU on digital sound coding standards. The intention was to have six sound channels within the 2.048 Mbit/s CCITT multiplex, each occupying at most five 64 kbit/s telephone channels each of

which had an additional 2 kbit/s 'channel associated signalling' capacity. A sampling rate of 32 kHz had been agreed but both instantaneous ('A-law') and near-instantaneous companding (NIC)[8] were under discussion. Parity protection was proposed for the more significant bits of each sample, but the scale factor (range word) for the NIC system was a problem. Only ten bits per 32-sample block were available to signal both parity and scale factor. A French proposal for scale factor and parity used the regular omission of alternate least significant bits of the ten-bit NIC samples to release a further 16 bits per block at the expense of quantising noise.

An internal BBC note describing how the scale factor might alternatively be signalled by systematically modifying the parity words was written. It proposed that there be up to ten parity bits per block, but that this ten-bit word be modified by bitwise modulo-two addition of one of seven code words according to which of five scale factors (A-E) or two other sound coding systems (such as 'A-law') was in use. The set of code words is reproduced as Table 1, note that the Hamming distance between codes is at least five and that the five scale factor codes are cyclic rotations of each other.

sound system Y:	0 0 0 0 0 0 0 0 0 0
scale factor A:	1 1 1 0 0 1 0 1 0 0
scale factor B:	1 1 0 0 1 0 1 0 0 1
scale factor C:	1 0 0 1 0 1 0 0 1 1
scale factor D:	0 0 1 0 1 0 0 1 1 1
scale factor E:	0 1 0 1 0 0 1 1 1 0
sound system Z:	1 1 1 1 1 1 1 1 1 1

Table 1: Set of seven code words from 1976 proposal.

This particular example would have operated well at low error rates, but people were already beginning to talk of error rates which would surely have shocked the original proponent of pulse-code modulation. (In later years, notably in discussions on direct broadcasting by satellite (DBS), useful operation would be expected even at bit error rates of 1 in 100.)

3.3 Extension of teletext character set

The original UK teletext system supported a 96-character set signalled by a seven-bit code with an eighth odd-parity bit. Odd parity rather than even was chosen to ensure that there was at least one data transition between the two binary levels in each serialised eight-bit word, which provided a worst-case interval of 14 clock periods between transitions to assist clock recovery circuits. Indeed, it was often said that odd parity was a necessary condition for this maximum interval between transitions when using eight-bit words whereas it is, in fact, a sufficient condition. The necessary condition is that the two eight-bit words 0000 0000 and 1111 1111 be unused.

Although not required in the specification, all mass-produced teletext decoders operated by clearing their page memories to the 'space' symbol, and then writing only and all relevant information satisfying the odd-parity check. This made it impossible to distinguish between receiving a transmitted row of 'space' symbols and failing to receive a row at all. Also the receiver would never complete the process of acquiring a page, it was always possible for an erroneous character with an even number of errors (satisfying the parity check) to overwrite previously correct information in the page memory.

A survey by the EBU of the character sets required by member countries using the Latin alphabet[9] identified a common-core of some 221 different characters (Table 2). Every combination of a letter and diacritical sign (accent) was counted as a separate entry. Such an extended character set, serving the needs of 25 major European languages at the same time, could be provided by the UK teletext system using an eight-bit code table and 'abolishing' odd-parity. This would have been fully compatible with the existing teletext decoders as the codes for their characters would be unchanged, and any 'new' characters would appear as blank spaces. Such a proposal was made[10] and a version with a 188-character set was recommended in a report[11] to the Commission of the European Community.

<table>
<tr><td>a</td><td>A</td><td>á</td><td>Á</td><td>à</td><td>À</td><td>â</td><td>Â</td><td>ä</td><td>Ä</td><td>ã</td><td>Ã</td><td>å</td><td>Å</td><td>æ</td><td>Æ</td><td>b</td></tr>
<tr><td>B</td><td>c</td><td>C</td><td>ć</td><td>Ć</td><td>č</td><td>Č</td><td>ç</td><td>Ç</td><td>d</td><td>D</td><td>đ</td><td>Đ</td><td>ð</td><td>e</td><td>E</td><td>é</td></tr>
<tr><td>É</td><td>è</td><td>È</td><td>ê</td><td>Ê</td><td>ë</td><td>Ë</td><td>ě</td><td>f</td><td>F</td><td>g</td><td>G</td><td>ğ</td><td>Ğ</td><td>ģ</td><td>Ģ</td><td>h</td></tr>
<tr><td>H</td><td>i</td><td>I</td><td>í</td><td>Í</td><td>ì</td><td>Ì</td><td>î</td><td>Î</td><td>ï</td><td>Ï</td><td>İ</td><td>ĳ</td><td>Ĳ</td><td>ı</td><td>j</td><td>J</td></tr>
<tr><td>k</td><td>K</td><td>l</td><td>L</td><td>ŀ</td><td>Ŀ</td><td>m</td><td>M</td><td>n</td><td>N</td><td>ń</td><td>ñ</td><td>Ñ</td><td>ň</td><td>ŋ</td><td>Ŋ</td><td>o</td></tr>
<tr><td>O</td><td>ó</td><td>Ó</td><td>ò</td><td>Ò</td><td>ö</td><td>Ö</td><td>ô</td><td>Ô</td><td>õ</td><td>Õ</td><td>ő</td><td>œ</td><td>Œ</td><td>ø</td><td>Ø</td><td>p</td></tr>
<tr><td>P</td><td>q</td><td>Q</td><td>r</td><td>R</td><td>ŕ</td><td>Ŕ</td><td>ř</td><td>Ř</td><td>s</td><td>S</td><td>ś</td><td>Ś</td><td>š</td><td>Š</td><td>ş</td><td>Ş</td></tr>
<tr><td>β</td><td>t</td><td>T</td><td>ŧ</td><td>Ŧ</td><td>þ</td><td>Þ</td><td>u</td><td>U</td><td>ú</td><td>Ú</td><td>ù</td><td>Ù</td><td>û</td><td>Û</td><td>ü</td><td>Ü</td></tr>
<tr><td>ű</td><td>v</td><td>V</td><td>w</td><td>W</td><td>ŵ</td><td>x</td><td>X</td><td>y</td><td>Y</td><td>ý</td><td>Ý</td><td>ŷ</td><td>z</td><td>Z</td><td>ź</td><td>Ź</td></tr>
<tr><td>ž</td><td>Ž</td><td></td><td>!</td><td>¡</td><td>"</td><td>'</td><td>(</td><td>)</td><td>,</td><td>-</td><td>.</td><td>/</td><td>:</td><td>;</td><td>?</td><td>¿</td></tr>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>^{0}</td><td>^{1}</td><td>^{2}</td><td>^{3}</td><td>¼</td><td>½</td><td>¾</td></tr>
<tr><td>+</td><td>±</td><td><</td><td>=</td><td>></td><td>÷</td><td>_</td><td>–</td><td>‾</td><td>|</td><td>‖</td><td>←</td><td>→</td><td>↑</td><td>↓</td><td>\</td><td>■</td></tr>
<tr><td>@</td><td>¤</td><td>£</td><td>$</td><td>₠</td><td>#</td><td>%</td><td>‰</td><td>&</td><td>*</td><td>º</td><td>ª</td><td>§</td><td>¶</td><td>α</td><td>μ</td><td>©</td></tr>
</table>

Table 2: The complete repertoire of Latin-based characters required by EBU Member organizations.

Parity having been removed, detailed proposals were made for methods of error protection appropriate to eight-bit teletext coding, based on the use of majority logic on repeated transmissions of a page, but without the need to store the entire page several times over. These ideas were received with interest by some, but a more common response to the removal of parity was "it is a trick" or "it is not in the textbooks". In February 1979 the attendees at the EBU working party on Data Broadcasting went to see the system demonstrated at Philips, Eindhoven. The protection had been augmented by a proposal (by Christis of Philips) whereby one or more extra data lines signalled explicitly in a very compact form the character cells in which 'even parity' was in use. The demonstration was very successful and one comment was "it is a trick, but it works".

At that time there was little support for experimental transmission of this potential new common European standard in the UK, so Philips directed their efforts to character set extension based on composition coding where there was no longer a one-to-one equivalence between codes and characters and where pages containing several accented letters would require more than the normal kilobyte of storage.

The option of using eight-bit coding within UK teletext still remains, however, within the broadcast software system currently in use,[12] although the necessary software is not at present provided in the Teletext Adapter for the BBC Microcomputer. The BBC 'Telesoftware' service, launched in September 1983, does not depend on parity and relies on the CRC for error control. Practical experience shows that this is a very reliable service.[13] It is likely that eight-bit coding will also be used for auxiliary teletext data lines unrelated to the conventional pages.

Direct eight-bit coding of an extended character set was subsequently accepted for the 32/64 character display of radiodata[14] and for the text of the service information (SI) in the EBU specification for DBS.[15]

3.4 Embedded check words for teletext pages

The original UK teletext specification did not provide for a cyclic redundancy check word[1] for checking the complete and correct reception of a page. When considering methods of sending this extra 16 bits of data without the overhead of an entire additional data line three possibilities were considered. One was to insert it at the end of the page header, but it would be very many years, if ever, before receivers ceased to rely on 'rolling' page headers for clock time. Another possibility was to put the CRC at the bottom right corner of the page as the last two characters of the line, preceded by a 'blue mosaic' or 'conceal' control character to reduce its visibility.

The third possibility was to take advantage of the great redundancy already within a teletext page to alter the codes within a page, without altering the appearance of the page, such that its CRC was constant (such as all zeroes) and thus need not be sent. One particular technique for doing this has been described[16] but the extent to which this can always be done without disturbing the editorial content of the page remains to be studied. This technique could be adapted to provide a 'watermark' to indicate the authenticity and origin of a teletext page.

3.5 Cycling sequences of modification

The idea of locking on to a fixed redundancy in a signal, such as a regular parity check, has already been described. This can be extended directly to lock to a more complicated redundancy, such as a CRC. Although this is a more complex operation than a parity check, both can be seen as a continuous process in which the check for any particular block is obtained as the bit-wise modulo-two sum (i.e. difference) of cumulative check words from a common but arbitrary origin – see *Fig. 3.* This shows how a check word is generated from a block of data and inserted in the transmitted signal. A decoder applies the check word operation continuously without resetting the process. The output is delayed for the period of one data block so the difference across a block is monitored. When there is correspondence with a true block this difference will be, typically, all zeroes and a flywheel synchroniser can lock on to this regular event and so recover block boundaries from the transmitted data.

Locking on to a CRC is attractive because arbitrary data is less and less likely to satisfy the CRC the longer check word becomes, whereas half of all arbitrary data will satisfy a simple parity check. Nevertheless, systematic effects can lead to a high probability that data offset by a few bit periods will still satisfy a CRC; methods of overcoming this problem have been described.[17]

When synchronisation is to be achieved in a regular data multiplex by locking on to a multi-bit check word it is possible to allow locking to a longer (subharmonic) periodicity in the multiplex by applying a systematic sequence of modification to the check words. The decoder can initially check for just one or possibly all versions at once, but once the pattern is established the system is as rugged as if the

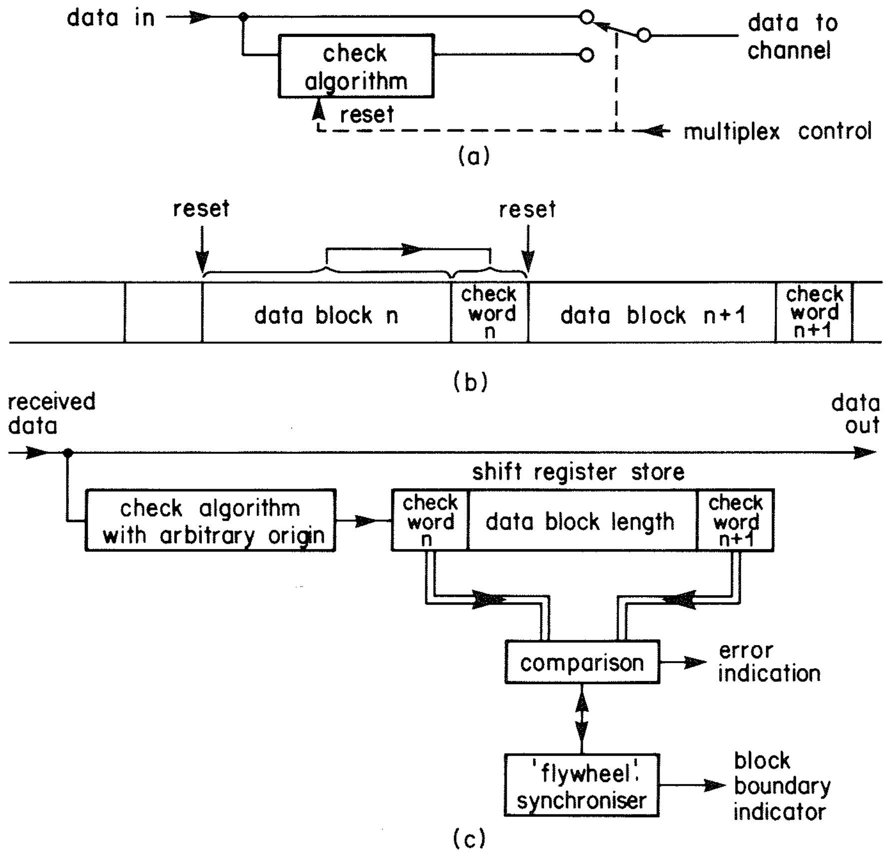

Fig. 3 – The principle of recovering block synchronisation implicit in the check words.
a) Generation and insertion of check word.
b) Format of transmitted signal.
c) Decoder to recover block boundaries.

modification were not there. Even if there is a loss of lock the 'flywheel' can usually predict which modification is next due in order to assist in reframing. The extra phasing information has been termed "something for nothing". This technique is used in the Radio-Data System specified by the EBU.[14]

As well as providing the means to synchronise to a longer-term regularity in a data multiplex a systematic modification of a check word can be used to provide a continuity index in a packet transmission system without requiring additional bits for this function.[18]

3.6 Synchronisation of 'structure map' multiplex

In one of the BBC proposals for a 'type A' 2.048 Mbit/s data multiplex for satellite broadcasting the data was organized into lines and frames rather like a television picture (*Fig. 4*). At the start of each line there would be one of two complementary framing codes. The decoder would respond to both and lock to their periodicity. As the framing code contained 16 bits the decoder could indicate reliably, at normal error rates, which of the two versions was present on each line. The sequence of

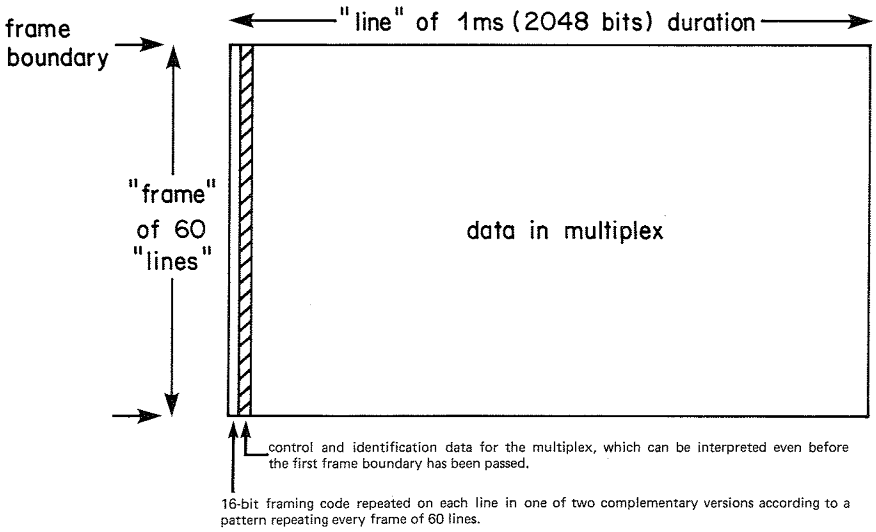

Fig. 4 – A proposed use of complemented framing codes to give rapid line and frame synchronisation in a 2048 kbit/s multiplex.

alternative framing codes followed a fixed pattern identifying the 60 lines of the frame. This pattern was a 'chain code'[19] in which any particular sequence of six consecutive bits occurred at a unique point in the sequence (Table 3). Such a sequence is easily generated at the source, and it is a simple matter to synchronise to the pattern in a receiver,[20] as will be shown in a later example.

1100010111	1001010001	1000010000	0111111010
1011001101	1101101001		

Table 3 : A 60-bit chain code.

So after only six or seven lines had been received it was possible to infer the position within the frame and so decode other specific information given in the control and identification data. The lock-up time was ten times faster than the worst case when relying on information at the frame boundary. Rapid lock-up is important in satellite broadcasting as, with many channels potentially present, it is important for a 'searching' receiver to be able quickly to reject unwanted channels in order to find the wanted one.

3.7 Synchronisation of the DBS packet multiplex

The packet multiplex specified by the EBU for direct broadcasting by satellite[15] uses a data burst at a regular position on every television line. The position of the television picture start is given by a discontinuity in the alternation between a pair of complementary line synchronising words together with a 64-bit Frame Synchronising Word in the data multiplex. These events occur only at picture boundaries. If the pattern of these alternative words followed a 625-bit chain code (Table 4) or, if necessary, a 1250-bit chain code (as there is a two-picture periodicity in the system), the decoder could acquire picture lock seventy times faster than the present worst case. This would allow a more rapid decoding of and response to the packet multiplex, and it would allow future television receivers (without field flyback) to present the picture more quickly.

1100000101	0110110011	0000110101	1011101000
1010111111	0100011100	1101110010	1000110100
0000110010	0100010000	0100110110	1001111001
1010101100	0010111011	0100011000	0100111111
1011100011	1100000011	1011011000	1010001001
1001000001	1010010011	1101111100	0101010110
1000010100	0000010110	1101111001	1110001000
1111110110	0011101011	0101000011	0011011000
0011000000	0011011011	0101110101	1110000101
0100100001	0110010011	0000010001	0010000001
0000000001	0010010011	0100110101	1111001100
0111110010	0011101111	1100001110	0000001111
1111110001	1100010011	1011001010	1110111101
0100011110	1001010100	0001011111	1110101010
1011110100	0011101001	0001100101	1010110011
1101011000	1100111111	00101	

Table 4 : A 625-bit chain code.

As well as providing synchronising information much more quickly, such a system, depending on information spread throughout the multiplex, and the result of all 625 signalling in parity majority logic decisions per picture instead of about four of them, offers a potentially more rugged system. The generator and locking mechanism for this particular sequence is shown in *Fig. 5*. The generator comprises a ten-bit shift register with modulo-two feedback from the third and tenth stages. The feedback signal is modified (a 1 is inserted in place of a 0) at one point in the sequence which would otherwise have a period of 1023 bits. The all-zero state could perpetuate in the shift register and a practical design must avoid this possibility. The same basic circuit is used in the decoder (Fig. 5(b)). The system is held open-loop (unlocked) until there is a match of at least ten consecutive bits. The comparator then closes the feedback loop but it continues to monitor the difference from the incoming chain code. In the absence of errors there will be complete agreement between the two. The state of the ten-bit register in either the generator or the decoder uniquely specifies the point in the 625-line sequence.

This technique of using a 'one-bit-per-line' chain code can be applied in any situations where there is little signalling capacity available and yet it is required to indicate the television line number (i.e. picture phase) as quickly as possible, even before a field interval has been reached.

3.8 Sound coding for EBU DBS specification

The signalling in parity principle was proposed for sending the scale factors in the NIC sound coding systems for the EBU specification for DBS.

When the technique was originally presented to the EBU specialist group it used the 32 simple parity bits of the 32 samples in one coding block. The scale factor was coded as a three-bit number and each bit was the result of the majority of nine parity checks (Fig. 6). This shows how each bit of the scale factor (11) is, nine times over, taken with the five most significant bits of samples in the NIC block (10) to form the modified parity bits (12). In the receiver the results of the parity checks of the samples (20) and modified parity bits (21) are gathered in the same

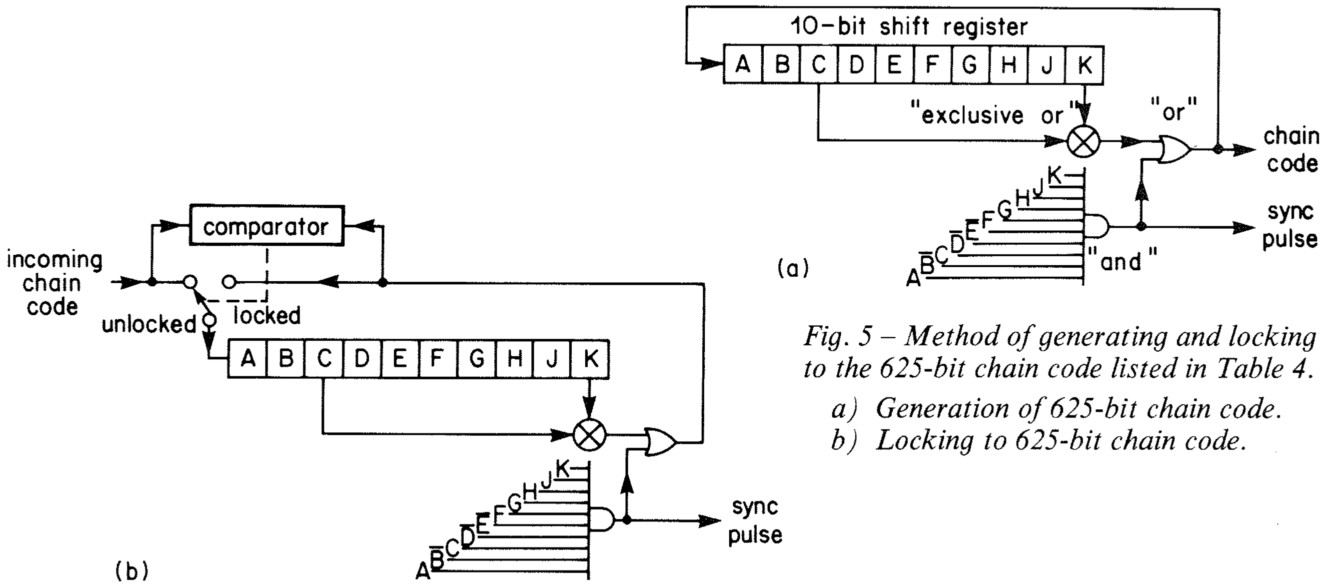

Fig. 5 – Method of generating and locking to the 625-bit chain code listed in Table 4.

a) Generation of 625-bit chain code.
b) Locking to 625-bit chain code.

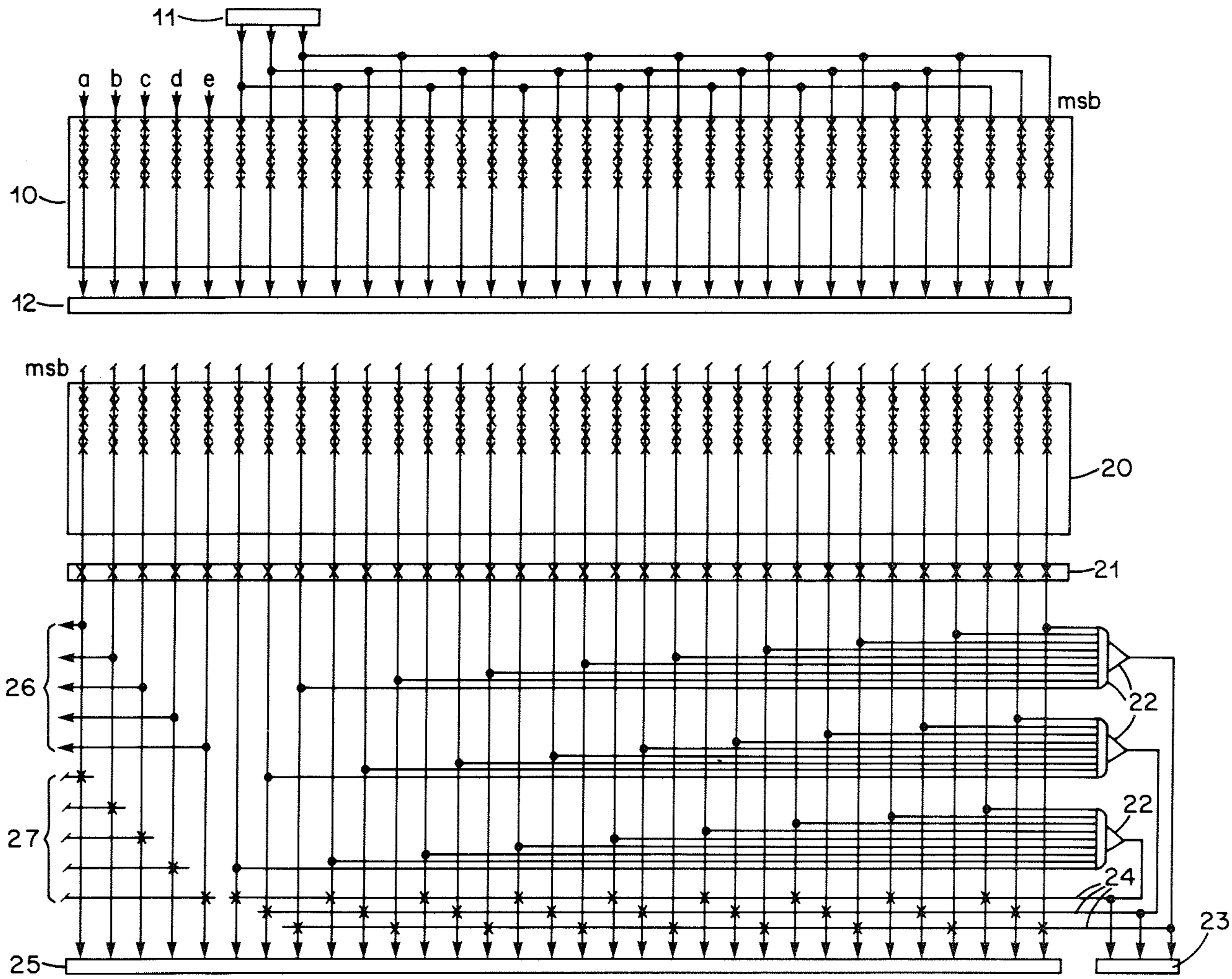

Fig. 6 – The signalling in parity system proposed for use in sending three-bit scale factors for the NIC sound coding systems for the EBU specification for DBS.

groups of nine by majority-logic gates (22) whose output (23) is taken to be the reconstituted scale factor. This is then used to modify the parity checks to give the conventional result (25).

It was pointed out that the remaining five bits (a–e) could be left alone, used to send auxiliary data (at lower reliability than the scale factor and at risk to the sound data), or added to the others to give 11 + 11 + 10 bits to decide the three scale factor bits. The calculated performance of such a system is indicated in Table 5.

$-\log_{10}$ of random bit error rate	$-\log_{10}$ of rate of wrong scale factors
large n	5n – 6.47
3.00	8.54
2.50	6.07
2.00	3.73

Table 5 : Protection of three-bit scale factor when each bit is majority-of-nine decision on parity bits each protecting five bits.

In subsequent discussions it became necessary to consider signalling a scale factor in only 16 simple parity bits of a group. Six 16-bit codes with Hamming distance of at least nine from each other were found and it was proposed that the parity modification and decision be based on these. The particular codes, listed in Table 6, were produced by an exhaustive search programmed on a BBC microcomputer as, at the time the question arose, the author did not have access to an alternative method of finding how large a set of 16-bit codes differing from all others of the set by a Hamming distance of at least nine could be found.

0000	0000	0000	0000
0000	0001	1111	1111
0011	1110	0000	1111
0101	1110	1111	0000
1110	0111	0011	0011
1110	1011	1100	1101

Table 6 : A set of six 16-bit numbers with Hamming distance of at least nine from each other.

Although only five scale factors were required at that time a sixth was proposed[21] to signal 'silence' to allow alternative data to be sent in that time slot. The calculated performance of this system is given in Table 7.

$-\log_{10}$ of random bit error rate	$-\log_{10}$ of rate of wrong scale factors
large n	5n – 8.85
3.00	6.21
2.50	3.79
2.00	1.71

Table 7 : Protection of one-of-six scale factor when using codes in Table 6 with each bit being a parity bit protecting ten bits.

The signalling in parity system was adopted in the EBU specification[15] for all four sound coding options originally provided. Two of these were linear coding systems, as it had been realised that a scale factor could be used to provide adjustable amplitude limits for the signal and so avoid high-amplitude errors in quiet sound passages. All of the four systems use majority-of-nine logic to give a three-bit scale factor.

In connection with the work of EBU Specialist Group R5/DQ a detailed study of the theoretical behaviour of the signalling in parity options used in the sound coding systems specified for the C-MAC/packet system was undertaken by Oliphant.[22] He presented calculations of the effect of the use of signalling in parity on the probability of undetected errors for two of the sound systems and concluded that, in these cases, it had negligible effect on the protection of the sound samples against errors as well as providing excellent protection for the scale factor information. Fig. 7, reproduced from his study, shows the effect of the use of signalling in parity on the probability of undetected erroneous samples with the two alternative protection methods available in the C-MAC/packet system.

3.9 Sound coding for digital stereo sound for television

Experimental BBC transmissions[23] of digital stereo sound for television now use a digital multiplex closely based on one of the sound coding options provided in the C-MAC/packet system. Near-instantaneous companding is used, with the scale factor protected by signalling in parity using the first level of protection. Preliminary results show tolerable performance even with an error rate of 1 in 200.

4. Future uses

One of the early objections to the practical use of signalling in parity was the complexity of the circuitry, often involving majority logic, required to decode the auxiliary data and recover the conventional error protection bits. The acceptance of the technique for applications involving mass-produced

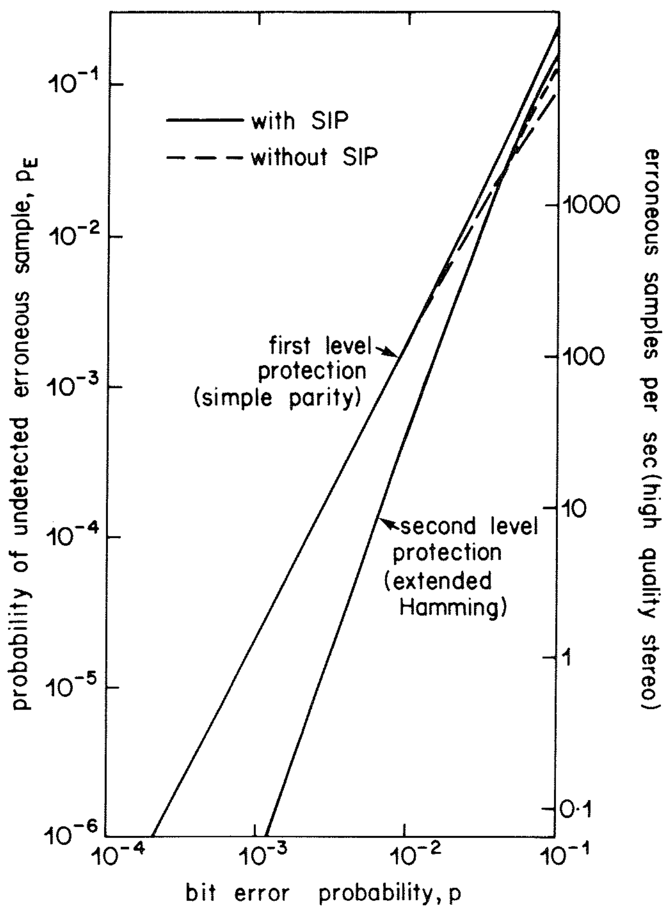

Fig. 7 – The effect of signalling in parity on the probability of undetected erroneous sound samples with the two alternative protection methods available in the C-MAC/packet system.

decoders suggests that this difficulty is no longer significant.

Although only modest additional data rates are made available the exceptional ruggedness of the data channel provided by signalling in parity makes it well suited to use in controlling important functions, such as the format of a data multiplex. It was in such an application that it was first used at BBC Engineering Research Department.

The powerful combination of signalling in parity with chain-code synchronisation is particularly relevant to the broadcasting environment where viewers change channels, and networks are switched, between sources of arbitrary phase. This will become still more significant when display devices are directly addressed rather than depending on scanning processes.

In most telecommunication systems time is not of the essence, and additional data, protected as necessary, can be inserted in a data stream. It is in the world of the broadcaster, where the flow of input audio or video is unstoppable, that the pressure to send additional data without using extra bits arises.

So the most probable future uses are in broadcast applications for control and synchronisation purposes associated with sound and television signals.

5. Conclusion

After many years of occasional use and discussion the technique of 'signalling-in-parity' is becoming accepted as a useful weapon in the battle to obtain the most efficient use of the data capacity available to broadcasters.

Examples have been given of the use of the technique to send control information and synchronising information in ways which are extremely rugged, efficient and, in the case of chain codes, ways which supply more information than the conventional approach.

Particular emphasis has been given to the use of the technique to send scale factors for sound coding where, in addition to increased efficiency, there is an improvement in performance under normal operational conditions.

6. References

1. BLEAZARD, G.B., 1982. Handbook of Data Communications. National Computing Centre. Manchester, 1982. ISBN 0-85012-363-1.

2. RATLIFF, P.A. *and* STOTT, J.H., 1983. Digital Television Transmission: 34 Mbit/s investigation. BBC Research Department Report No. 1983/9.

3. CHEW, J.R. *and* MOFFAT, M.E.B., 1972. Pulse Code Modulation for High Quality Sound–Signal Distribution: protection against digit errors. BBC Research Department Report No. 1972/18.

4. CLARKE, C.K.P., 1977. Digital Television: the use of waveform estimates in error correction. BBC Research Department Report No. 1977/27.

5. CHAMBERS, J.P., 1985. Improvements Relating to Digital Data Transmission. U.K. Patent Specification GB 2 116 403B 23rd October 1985.

6. OSBORNE, D.W., 1976. Experimental Digital Transmission of Multiplexed Video and Audio Signals at 120 Mbit/s. BBC Research Department Report No. 1976/16.

7. STOTT, J.H., 1978. Design Technique for Multiplexing Asynchronous Digital Video and Audio Signals. *IEEE Trans. Com.*, **Vol. COM-26,** No. 5, May 1978, pp. 601–610.

8. CROLL, M.G., MOFFAT, M.E.B. *and* OSBORNE, D.W., 1973. 'Nearly-instantaneous' digital compandor for transmitting six sound-programme signals in a 2.048 Mbit/s multiplex. *Electronics Letters*, **Vol. 9,** No. 14, 12th July 1973, pp. 298–300.

9. EBU, 1982. Displayable Character Sets for Broadcast Teletext. EBU document Tech. 3232, June 1982.

10. CHAMBERS, J.P., 1979. Teletext alphabets and error protection. EBU Review (Technical), No. 173, February 1979, pp. 25–29.

11. McGREGOR ROSS, H., 1979. Character Sets for Communication of Text. Final Report prepared for The Commission of the European Communities Directorate General for Scientific and Technical Information and Information Management. May 1979.

12. RAYERS, D.J., 1984. The UK Teletext Standard for Telesoftware Transmission. IERE Publication No. 60, *Telesoftware*, September 1984, pp. 1–8.

13. BROWN, L., 1984. Telesoftware: experiences of providing a broadcast service. *Ibid*, pp. 25–28.

14. EBU, 1984. Specification of the radio data system RDS for VHF/FM sound broadcasting. EBU document Tech. 3244, March 1984.

15. MERTENS, H. *and* WOOD, D., 1983. The C-MAC/packet system for direct satellite television. EBU Review (Technical), No. 200, August 1983, pp. 172–185.

16. CHAMBERS, J.P., 1982. Cyclic Redundancy Data Check Encoding Method and Apparatus. UK Patent Specification GB 2 035 014 B. 28th September 1982.

17. ELY, S.R. *et al.*, 1983. High Speed Decoding Technique for Slip Detection in Data Transmission Systems using Modified Cyclic Block Codes. *Electronics Letters*, **Vol. 19,** No. 3, 3rd February 1983.

18. CHAMBERS, J.P., 1985. Digital Data Coding. UK Patent Application GB 85/11804.

19. HEATH, F.G. *and* GRIBBLE, M.W., 1961. Chain Codes and their Electronic Applications. *Proc. IEE*, **Vol. 108,** Part C, pp. 50–57.

20. CHAMBERS, J.P., 1984. Data Transmission. UK Patent Application GB 2 124 807 A. 22nd February 1984.

21. CHAMBERS, J.P., 1984. Digital Data Coding. UK Patent Application GB 2 125 255 A. 29th February 1984.

22. OLIPHANT, A., 1986. The effect of transmission errors on sound signals in the C, D and D2-MAC/packet systems. EBU Review (Technical), No. 215, February 1986.

23. JONES, A.H., 1985. Digital Stereo Sound with Terrestrial Television. Society of Motion Picture and Television Engineers 19th Annual Television Conference. San Francisco, 15th–16th February 1985. SMPTE conference publication *Components of the Future*, pp. 316–324.